Super Charged Unit Analysis

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Introduction

Unit analysis converts one unit to another by multiplying by *conversion factors* that equal 1. At each step, the "old" unit *crosses out* with the same unit in the denominator. In this packet, you may assume no outside formulas are needed: every numerical equivalence you need appears either in a local Data Box or in the **Giant Master Table** at the end of this packet. Keep that table open while you work.

How to show your work (always include the units):

1. Write the given quantity with its unit.
2. Multiply by conversion factors written as fractions so that unwanted units cancel.
3. Continue until only the desired unit remains, then compute the number.

Example (with crosses): Converting 1 day **to seconds**

$$1\,\text{day} \times \frac{24\,\text{h}}{\cancel{1\,\text{day}}} \times \frac{60\,\text{min}}{\cancel{1\,\text{h}}} \times \frac{60\,\text{s}}{\cancel{1\,\text{min}}} = 86{,}400\,\text{s}.$$

Problems — Intermediate

I1. A car's fuel tank holds 12.5 US gal of gasoline. Using the *Data Box* energy density, convert this to kWh and BTU.

Plan. Convert gallons → liters → megajoules → joules, then to kWh and BTU. Use the Data Box: gasoline $\approx 34.2\,\text{MJ/L}$.

$$\begin{aligned} E(\text{J}) &= \underbrace{12.5\,\text{gal}}_{\text{given}} \times \frac{3.78541\,\text{L}}{\cancel{1\,\text{gal}}} \times \frac{34.2\,\text{MJ}}{\cancel{1\,\text{L}}} \times \frac{10^6\,\text{J}}{\cancel{1\,\text{MJ}}} \\ &\approx 1.62 \times 10^9\,\text{J}. \end{aligned}$$

To kWh:

$$1.62 \times 10^9\,\text{J} \times \frac{1\,\text{kWh}}{3.6 \times 10^6\,\cancel{\text{J}}} \approx 4.50 \times 10^2\,\text{kWh}.$$

To BTU:

$$1.62 \times 10^9\,\text{J} \times \frac{1\,\text{BTU}}{1055.06\,\cancel{\text{J}}} \approx 1.53 \times 10^6\,\text{BTU}.$$

I2. Convert 1.85 atm to psi, kPa, and mmHg.

Solution.

$$1.85\,\text{atm} \times \frac{101{,}325\,\text{Pa}}{\cancel{1\,\text{atm}}} = 187{,}451\,\text{Pa} = 187.5\,\text{kPa}.$$

$$187{,}451\,\text{Pa} \times \frac{1\,\text{psi}}{6894.76\,\cancel{\text{Pa}}} = 27.2\,\text{psi}. \qquad 1.85\,\text{atm} \times \frac{760\,\text{mmHg}}{\cancel{1\,\text{atm}}} = 1406\,\text{mmHg}.$$

I3. A laboratory recipe calls for 250 mg of glucose per dL of solution. Convert this to g/L and kg/m^3.

Solution.

$$250\,\mathrm{mg/dL} \times \frac{1\,\mathrm{g}}{1000\,\cancel{\mathrm{mg}}} = 0.250\,\mathrm{g/dL}. \quad 0.250\,\mathrm{g/dL} \times \frac{10\,\mathrm{dL}}{1\,\mathrm{L}} = 2.50\,\mathrm{g/L} = 2.50\,\mathrm{kg/m^3}.$$

I4. Convert a flow rate of 3.25 ft^3/min to L/s.

Solution.

$$3.25\,\frac{\mathrm{ft^3}}{\mathrm{min}} \times \frac{28.3168\,\mathrm{L}}{\cancel{1\,\mathrm{ft^3}}} \times \frac{1\,\mathrm{min}}{60\,\mathrm{s}} = 1.54\,\mathrm{L/s}.$$

I5. A material is specified at 4.7 oz/yd^2. Express this as g/m^2.

Solution.

$$4.7\,\frac{\mathrm{oz}}{\mathrm{yd^2}} \times \frac{28.3495\,\mathrm{g}}{\cancel{1\,\mathrm{oz}}} = 133.24\,\frac{\mathrm{g}}{\mathrm{yd^2}}.$$

$$1\,\mathrm{yd^2} = (0.9144\,\mathrm{m})^2 = 0.83613\,\mathrm{m^2} \Rightarrow \frac{133.24\,\mathrm{g}}{0.83613\,\mathrm{m^2}} = 1.59 \times 10^2\,\mathrm{g/m^2}.$$

I6. An oil barrel is 42 US gal. How many cubic meters is 120 barrels?

Solution.

$$120\,\mathrm{bbl} \times \frac{42\,\mathrm{gal}}{\cancel{1\,\mathrm{bbl}}} \times \frac{3.78541\,\mathrm{L}}{\cancel{1\,\mathrm{gal}}} \times \frac{1\,\mathrm{m^3}}{1000\,\cancel{\mathrm{L}}} = 19.1\,\mathrm{m^3}.$$

I7. Convert 750 mL to in^3 and ft^3.

Solution.

$$750\,\mathrm{mL} = 750\,\mathrm{cm^3} \times \frac{1\,\mathrm{in^3}}{16.387\,\cancel{\mathrm{cm^3}}} = 45.8\,\mathrm{in^3}, \quad 45.8\,\mathrm{in^3} \times \frac{1\,\mathrm{ft^3}}{1728\,\cancel{\mathrm{in^3}}} = 2.65 \times 10^{-2}\,\mathrm{ft^3}.$$

I8. A sample is labeled 1.5 g/cm^3. Convert this to lb/ft^3.

Solution.

$$1.5\,\frac{\mathrm{g}}{\mathrm{cm^3}} \times \frac{1\,\mathrm{lb}}{453.59237\,\cancel{\mathrm{g}}} \times \frac{(2.54\,\mathrm{cm})^3}{1\,\mathrm{in^3}} \times \frac{1728\,\mathrm{in^3}}{1\,\mathrm{ft^3}} = 93.6\,\mathrm{lb/ft^3}.$$

I9. A battery stores 85 Wh. Express this as kJ and BTU.

Solution.

$$85\,\mathrm{Wh} \times \frac{3600\,\mathrm{J}}{1\,\mathrm{Wh}} = 3.06 \times 10^5\,\mathrm{J} = 306\,\mathrm{kJ}, \quad 306{,}000\,\mathrm{J} \times \frac{1\,\mathrm{BTU}}{1055.06\,\cancel{\mathrm{J}}} = 2.90 \times 10^2\,\mathrm{BTU}.$$

I10. Convert 2.00 eV (per particle) into kJ/mol.

Solution.

$$2.00\,\mathrm{eV} \times \frac{1.602 \times 10^{-19}\,\mathrm{J}}{\cancel{1\,\mathrm{eV}}} \times \frac{6.022 \times 10^{23}\,\mathrm{particles}}{1\,\mathrm{mol}} = 1.93 \times 10^5\,\mathrm{J/mol} = 193\,\mathrm{kJ/mol}.$$

Problems — Advanced

A1. A drum of mercury is "55 gallons, full." Using the *Data Box* density, find the mass in kg and in tons (US short).

Plan. Convert volume (gal → L → cm^3), multiply by density to get mass in g, then to kg and US short tons.

$$V(\text{cm}^3) = \underbrace{55\,\text{gal}}_{\text{given}} \times \frac{3.78541\,\text{L}}{1\,\cancel{\text{gal}}} \times \frac{1000\,\text{cm}^3}{1\,\cancel{\text{L}}}$$
$$\approx 2.082 \times 10^5\,\text{cm}^3.$$

$$m(\text{g}) = V \times \rho = \left(2.082 \times 10^5\,\text{cm}^3\right) \times \frac{13.6\,\text{g}}{\cancel{\text{cm}^3}} \approx 2.83 \times 10^6\,\text{g}.$$

$$\frac{2.83 \times 10^6\,\text{g}}{1000\,\cancel{\text{g}}/\text{kg}} = 2.83 \times 10^3\,\text{kg}, \qquad 2.83 \times 10^3\,\text{kg} \times \frac{2.20462\,\text{lb}}{1\,\cancel{\text{kg}}} \times \frac{1\,\text{ton}}{2000\,\cancel{\text{lb}}} \approx 3.12\,\text{ton}.$$

A2. A nutrition label states 200 kcal per serving. Convert this to kJ, BTU, and kWh.

Solution.

$$200\,\text{kcal} \times \frac{4184\,\text{J}}{1\,\cancel{\text{kcal}}} = 836{,}800\,\text{J} = 836.8\,\text{kJ}. \quad \frac{836{,}800\,\text{J}}{1055.06\,\text{J/BTU}} = 793\,\text{BTU}. \quad \frac{836{,}800\,\text{J}}{3.6 \times 10^6\,\text{J/kWh}} = 0.232\,\text{kWh}.$$

A3. A pressure gauge reads 36.5 psi. Express this pressure in Pa, kPa, bar, and atm.

Solution.

$$36.5\,\text{psi} \times \frac{6894.76\,\text{Pa}}{1\,\cancel{\text{psi}}} = 251{,}659\,\text{Pa} = 251.7\,\text{kPa}.$$

$$251{,}659\,\text{Pa} \times \frac{1\,\text{bar}}{100{,}000\,\cancel{\text{Pa}}} = 2.52\,\text{bar}, \qquad 251{,}659\,\text{Pa} \times \frac{1\,\text{atm}}{101{,}325\,\cancel{\text{Pa}}} = 2.48\,\text{atm}.$$

A4. A material lists surface density $12.0\,\text{mg/cm}^2$. Convert to kg/m^2 and to oz/yd^2.

Solution.

$$12.0\,\frac{\text{mg}}{\text{cm}^2} \times \frac{1\,\text{g}}{1000\,\cancel{\text{mg}}} = 0.0120\,\text{g/cm}^2.$$

$$0.0120\,\frac{\text{g}}{\text{cm}^2} \times \frac{10^4\,\text{cm}^2}{1\,\text{m}^2} \times \frac{1\,\text{kg}}{1000\,\cancel{\text{g}}} = 0.120\,\text{kg/m}^2.$$

$$0.120\,\frac{\text{kg}}{\text{m}^2} \times \frac{35.274\,\text{oz}}{1\,\cancel{\text{kg}}} \times \frac{1\,\text{m}^2}{1.19599\,\cancel{\text{yd}^2}} = 3.54\,\text{oz/yd}^2.$$

A5. A tank holds $2.40\,\text{m}^3$ of ethanol. Using the *Data Box* energy density (30.0 MJ/L), estimate the energy content in GJ and MWh.

Solution.

$$2.40\,\text{m}^3 \times \frac{1000\,\text{L}}{1\,\cancel{\text{m}^3}} = 2400\,\text{L}. \quad 2400\,\text{L} \times \frac{30.0\,\text{MJ}}{1\,\cancel{\text{L}}} = 72{,}000\,\text{MJ} = 72\,\text{GJ}.$$

$$72 \times 10^9\,\text{J} \times \frac{1\,\text{MWh}}{3.6 \times 10^9\,\cancel{\text{J}}} = 20.0\,\text{MWh}.$$

A6. A radiation dose of 350 mrad is absorbed by a 70.0 kg patient. How many joules are absorbed?

Solution.

$$350\,\text{mrad} \times \frac{1\,\text{rad}}{1000\,\cancel{\text{mrad}}} \times \frac{0.01\,\text{Gy}}{1\,\cancel{\text{rad}}} = 0.00350\,\text{Gy} = 0.00350\,\frac{\text{J}}{\text{kg}}.$$

$$0.00350\,\frac{\text{J}}{\text{kg}} \times 70.0\,\text{kg} = 0.245\,\text{J}.$$

A7. A catalyst loading is specified as 0.75 g per 100 cm^2. Express as mg/in^2 and kg/m^2.

Solution.

$$\frac{0.75\,\text{g}}{100\,\text{cm}^2} = 7.5\,\frac{\text{mg}}{\text{cm}^2}. \quad 7.5\,\frac{\text{mg}}{\text{cm}^2} \times \frac{6.4516\,\text{cm}^2}{1\,\text{in}^2} = 48.4\,\text{mg/in}^2.$$

$$7.5\,\frac{\text{mg}}{\text{cm}^2} \times \frac{10^4\,\text{cm}^2}{1\,\text{m}^2} \times \frac{1\,\text{kg}}{10^6\,\cancel{\text{mg}}} = 0.075\,\text{kg/m}^2.$$

A8. A solution contains 0.250 mol/L sucrose. Using *Data Box* molar mass, convert this to g/L and mg/mL.

Solution.

$$0.250\,\frac{\text{mol}}{\text{L}} \times \frac{342.30\,\text{g}}{1\,\cancel{\text{mol}}} = 85.6\,\text{g/L} = 85.6\,\text{mg/mL}.$$

A9. A heating element is rated at 1.50 kW. How many BTU does it deliver in 25.0 min?

Solution.

$$1.50\,\frac{\text{kJ}}{\text{s}} \times 25.0\,\text{min} \times \frac{60\,\text{s}}{1\,\text{min}} = 2.25 \times 10^3\,\text{kJ} = 2.25 \times 10^6\,\text{J}.$$

$$2.25 \times 10^6\,\text{J} \times \frac{1\,\text{BTU}}{1055.06\,\cancel{\text{J}}} = 2.13 \times 10^3\,\text{BTU}.$$

A10. Express 7.80×10^{22} molecules of water as mol and as g.

Solution.

$$\frac{7.80 \times 10^{22}\,\text{molecules}}{6.022 \times 10^{23}\,\text{molecules/mol}} = 0.129\,\text{mol}. \quad 0.129\,\text{mol} \times \frac{18.015\,\text{g}}{1\,\cancel{\text{mol}}} = 2.32\,\text{g}.$$

Problems — Challenge (All Unit Chains)

C1. A refinery ships 1.25×10^6 bbl of diesel per month. Convert this to m^3/day and L/s.

Plan. Barrels → gal → L → m^3; then per day; then L/s.

$$\frac{\mathrm{m}^3}{\mathrm{day}} = 1.25 \times 10^6\,\mathrm{bbl} \times \frac{42\,\mathrm{gal}}{1\,\cancel{\mathrm{bbl}}} \times \frac{3.78541\,\mathrm{L}}{1\,\cancel{\mathrm{gal}}} \times \frac{1\,\mathrm{m}^3}{1000\,\cancel{\mathrm{L}}} \times \frac{1}{30\,\mathrm{day}} \approx 6.62 \times 10^3\,\frac{\mathrm{m}^3}{\mathrm{day}}.$$

$$\frac{\mathrm{L}}{\mathrm{s}} = 6.62 \times 10^6\,\frac{\mathrm{L}}{\mathrm{day}} \times \frac{1\,\mathrm{day}}{86400\,\mathrm{s}} \approx 7.67 \times 10^1\,\frac{\mathrm{L}}{\mathrm{s}} = 76.7\,\mathrm{L/s}.$$

C2. An electron beam deposits energy at 4.5 MeV per particle. Convert this to kJ/mol and to BTU/mol.

Solution.

$$4.5\,\mathrm{MeV} \times \frac{10^6\,\mathrm{eV}}{1\,\cancel{\mathrm{MeV}}} \times \frac{1.602 \times 10^{-19}\,\mathrm{J}}{1\,\cancel{\mathrm{eV}}} \times \frac{6.022 \times 10^{23}\,\mathrm{particles}}{1\,\mathrm{mol}} = 4.34 \times 10^{11}\,\mathrm{J/mol} = 4.34 \times 10^8\,\mathrm{kJ/mol}.$$

$$4.34 \times 10^{11}\,\mathrm{J/mol} \times \frac{1\,\mathrm{BTU}}{1055.06\,\cancel{\mathrm{J}}} = 4.11 \times 10^8\,\mathrm{BTU/mol}.$$

C3. A composite sheet is specified at $210\,\mathrm{g/m}^2$. How many pounds does a $12\,\mathrm{ft} \times 30\,\mathrm{ft}$ sheet weigh?

Solution.

$$12 \times 30 = 360\,\mathrm{ft}^2 \times \frac{1\,\mathrm{m}^2}{10.764\,\cancel{\mathrm{ft}^2}} = 33.5\,\mathrm{m}^2.$$

$$210\,\frac{\mathrm{g}}{\mathrm{m}^2} \times 33.5\,\mathrm{m}^2 = 7035\,\mathrm{g} = 7.04\,\mathrm{kg} \times \frac{2.20462\,\mathrm{lb}}{1\,\cancel{\mathrm{kg}}} = 15.5\,\mathrm{lb}.$$

C4. A solution has nitrate at 12.0 mg/L. What is this in ppm by mass *assuming water density* 1.00 kg/L?

Solution.

$$12.0\,\frac{\mathrm{mg}}{\mathrm{L}} \times \frac{1\,\mathrm{L}}{1.00\,\mathrm{kg}} = 12.0\,\frac{\mathrm{mg}}{\mathrm{kg}} = 12.0\,\mathrm{ppm}.$$

C5. A powerplant output is 650 MW. Express the daily energy production in GJ/day, MWh/day, and tons TNT/day.

Solution.

$$650 \times 10^6\,\frac{\mathrm{J}}{\mathrm{s}} \times 86400\,\mathrm{s} = 5.62 \times 10^{13}\,\mathrm{J/day}.$$

$$\frac{5.62 \times 10^{13}\,\mathrm{J}}{10^9\,\mathrm{J/GJ}} = 5.62 \times 10^4\,\mathrm{GJ/day}, \quad \frac{5.62 \times 10^{13}}{3.6 \times 10^6} = 1.56 \times 10^4\,\mathrm{MWh/day}, \quad \frac{5.62 \times 10^{13}}{4.184 \times 10^9} = 1.34 \times 10^4\,\text{tons TNT/d}$$

C6. A laboratory cylinder holds 3.75 L of dry wood chips (bulk). If the effective energy density is 4.0 MJ/L (voids included), find the energy in kWh and BTU.

Solution.

$$3.75\,\mathrm{L} \times \frac{4.0\,\mathrm{MJ}}{1\,\cancel{\mathrm{L}}} = 15.0\,\mathrm{MJ} = 1.50 \times 10^{7}\,\mathrm{J}.$$

$$1.50 \times 10^{7}\,\mathrm{J} \times \frac{1\,\mathrm{kWh}}{3.6 \times 10^{6}\,\cancel{\mathrm{J}}} = 4.17\,\mathrm{kWh}, \quad 1.50 \times 10^{7}\,\mathrm{J} \times \frac{1\,\mathrm{BTU}}{1055.06\,\cancel{\mathrm{J}}} = 1.42 \times 10^{4}\,\mathrm{BTU}.$$

C7. A pipeline carries 2.20 m^3/min of water. Convert this to US gal/s and ft^3/h.

Solution.

$$2.20\,\frac{\mathrm{m}^3}{\mathrm{min}} \times \frac{1000\,\mathrm{L}}{1\,\cancel{\mathrm{m}^3}} \times \frac{1\,\mathrm{gal}}{3.78541\,\cancel{\mathrm{L}}} \times \frac{1\,\mathrm{min}}{60\,\mathrm{s}} = 9.69\,\mathrm{gal/s}.$$

$$2.20\,\frac{\mathrm{m}^3}{\mathrm{min}} \times \frac{35.3147\,\mathrm{ft}^3}{1\,\cancel{\mathrm{m}^3}} \times 60\,\frac{\mathrm{min}}{\mathrm{h}} = 4.66 \times 10^{3}\,\mathrm{ft}^3/\mathrm{h}.$$

C8. A pressure transducer outputs 0.875 bar. Report in atm, psi, and torr.

Solution.

$$0.875\,\mathrm{bar} \times \frac{1\,\mathrm{atm}}{1.01325\,\cancel{\mathrm{bar}}} = 0.864\,\mathrm{atm}. \quad 0.875\,\mathrm{bar} \times \frac{100{,}000\,\mathrm{Pa}}{1\,\cancel{\mathrm{bar}}} \times \frac{1\,\mathrm{psi}}{6894.76\,\cancel{\mathrm{Pa}}} = 12.7\,\mathrm{psi}.$$

$$0.875\,\mathrm{bar} \times \frac{1\,\mathrm{atm}}{1.01325\,\cancel{\mathrm{bar}}} \times \frac{760\,\mathrm{torr}}{1\,\cancel{\mathrm{atm}}} = 656\,\mathrm{torr}.$$

C9. A sample of lead has volume 125 cm^3. Using *Data Box* density, find the mass in lb.

Solution.

$$11.34\,\frac{\mathrm{g}}{\mathrm{cm}^3} \times 125\,\mathrm{cm}^3 = 1417.5\,\mathrm{g} = 1.4175\,\mathrm{kg} \times \frac{2.20462\,\mathrm{lb}}{1\,\cancel{\mathrm{kg}}} = 3.13\,\mathrm{lb}.$$

C10. A tiny laser pulse carries 2.0 mJ. How many eV is this per photon if there are 5.0×10^{12} photons in the pulse?

Solution.

$$\frac{2.0 \times 10^{-3}\,\mathrm{J}}{5.0 \times 10^{12}} = 4.0 \times 10^{-16}\,\mathrm{J/photon} \times \frac{1\,\mathrm{eV}}{1.602 \times 10^{-19}\,\cancel{\mathrm{J}}} = 2.50 \times 10^{3}\,\mathrm{eV} = 2.50\,\mathrm{keV}.$$

C11. A roll of foil is 18 in wide, thickness 15 μm, and mass 1.25 kg. Estimate its length in m assuming density 2.70 g/cm^3 (aluminum).

Solution.

$$1.25\,\mathrm{kg} \times \frac{1000\,\mathrm{g}}{1\,\cancel{\mathrm{kg}}} \times \frac{1\,\mathrm{cm}^3}{2.70\,\cancel{\mathrm{g}}} = 4.63 \times 10^{2}\,\mathrm{cm}^3.$$

$$18\,\mathrm{in} \times \frac{2.54\,\mathrm{cm}}{1\,\cancel{\mathrm{in}}} = 45.72\,\mathrm{cm}, \quad 15\,\mu\mathrm{m} \times \frac{1\,\mathrm{cm}}{10^4\,\cancel{\mu\mathrm{m}}} = 1.5 \times 10^{-3}\,\mathrm{cm}.$$

$$A = 45.72\,\mathrm{cm} \times 1.5 \times 10^{-3}\,\mathrm{cm} = 6.858 \times 10^{-2}\,\mathrm{cm}^2, \quad L = \frac{4.63 \times 10^{2}\,\cancel{\mathrm{cm}^3}}{6.858 \times 10^{-2}\,\cancel{\mathrm{cm}^2}} = 6.75 \times 10^{3}\,\mathrm{cm} = 67.5\,\mathrm{m}.$$

C12. A syrup is 1.35 g/mL. How many liters are needed to supply 250 kg of syrup?

Solution.

$$250\,\mathrm{kg} \times \frac{1000\,\mathrm{g}}{1\,\cancel{\mathrm{kg}}} \times \frac{1\,\mathrm{mL}}{1.35\,\cancel{\mathrm{g}}} = 1.85185 \times 10^{5}\,\mathrm{mL} = 185.2\,\mathrm{L}.$$

C13. Convert 5.00 ly to light-minutes, then to km.

Solution.

$$5.00\,\mathrm{ly} \times \frac{365\,\mathrm{days}}{1\,\cancel{\mathrm{yr}}} \times \frac{24\,\mathrm{h}}{1\,\cancel{\mathrm{day}}} \times \frac{60\,\mathrm{min}}{1\,\cancel{\mathrm{h}}} = 2.63 \times 10^{6}\,\text{light-min}.$$

$$5.00\,\mathrm{ly} \times \frac{9.46 \times 10^{15}\,\mathrm{m}}{1\,\cancel{\mathrm{ly}}} \times \frac{1\,\mathrm{km}}{1000\,\cancel{\mathrm{m}}} = 4.73 \times 10^{13}\,\mathrm{km}.$$

C14. A fertilizer states 46% N by mass. How many grams of nitrogen are in 25.0 lb of fertilizer?

Solution.

$$25.0\,\mathrm{lb} \times \frac{453.59237\,\mathrm{g}}{1\,\cancel{\mathrm{lb}}} = 11{,}339.8\,\mathrm{g} \times 0.46 = 5{,}216\,\mathrm{g\ N}.$$

C15. A beverage contains 55 mg caffeine per 355 mL. Find mg/L, μg/mL, and grains/gal (1 grain = 64.79891 mg).

Solution.

$$\frac{55\,\mathrm{mg}}{355\,\mathrm{mL}} \times \frac{1000\,\mathrm{mL}}{1\,\mathrm{L}} = 155\,\mathrm{mg/L} = 0.155\,\mathrm{mg/mL} = 155\,\mu\mathrm{g/mL}.$$

$$155\,\frac{\mathrm{mg}}{\mathrm{L}} \times 3.78541\,\frac{\mathrm{L}}{\mathrm{gal}} \times \frac{1\,\mathrm{grain}}{64.79891\,\cancel{\mathrm{mg}}} = 9.06\,\mathrm{grains/gal}.$$

C16. A textile line runs at 120 m/min. Convert to mph and to ft/s.

Solution.

$$120\,\frac{\mathrm{m}}{\mathrm{min}} \times \frac{60\,\mathrm{min}}{1\,\mathrm{h}} \times \frac{1\,\mathrm{mi}}{1609\,\cancel{\mathrm{m}}} = 4.47\,\mathrm{mph}.$$

$$120\,\frac{\mathrm{m}}{\mathrm{min}} \times \frac{1\,\mathrm{min}}{60\,\mathrm{s}} \times \frac{3.28084\,\mathrm{ft}}{1\,\cancel{\mathrm{m}}} = 6.56\,\mathrm{ft/s}.$$

C17. A light pulse spans 350 ns. Express its duration in light-meters and light-feet.

Solution.

$$350 \times 10^{-9}\,\mathrm{s} \times 299{,}792{,}458\,\frac{\mathrm{m}}{\mathrm{s}} = 1.05 \times 10^{2}\,\mathrm{m} = 105\,\mathrm{m}. \quad 105\,\mathrm{m} \times \frac{3.28084\,\mathrm{ft}}{1\,\cancel{\mathrm{m}}} = 3.44 \times 10^{2}\,\mathrm{ft}.$$

Unit Analysis — Giant Master Table

SI Prefixes (Name, Symbol, Factor)

pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Time
60 s (seconds) = 1 min (minute)
60 min (minutes) = 1 h (hour)
24 h (hours) = 1 day
365 days ≈ 1 yr (year)

Length
1 in (inch) = 2.54 cm (centimetre) *exact*
12 in = 1 ft (foot); 3 ft = 1 yd (yard)
5280 ft = 1 mi (mile)
1 km (kilometre) = 1000 m (metre)
1 Å (ångström) = 10^{-10} m; 1 nm (nanometre) = 10^{-9} m
1 μm (micrometre) = 10^{-6} m
1 AU (astronomical unit) ≈ 1.496×10^{11} m
1 ly (light-year) ≈ 9.46×10^{15} m

Area
1 m^2 ≈ 10.764 ft^2 (square feet)
1 cm^2 ≈ 0.1550 in^2 (square inches)
1 acre = 43,560 ft^2

Volume
1 L (litre) = 1000 mL (millilitres) = 1000 cm^3 (cubic cm)
1 m^3 (cubic metre) = 1000 L
1 in^3 = 16.387 cm^3
1 ft^3 = 28.3168 L
1 gal (US gallon) = 231 in^3 ≈ 3.78541 L
1 qt = 0.94635 L; 1 cup = 236.588 mL
1 bbl (oil barrel) = 42 US gal

Mass
1 kg (kilogram) = 1000 g (grams)
1 lb (pound) = 453.59237 g *exact*
1 oz (ounce) = 28.3495 g
1 t (metric tonne) = 1000 kg
1 ton (US short ton) = 2000 lb
1 u (atomic mass unit) = 1.66054×10^{-27} kg

Density
Water (at 20°C): 1.00 g/cm^3 = 1000 kg/m^3

Pressure
1 atm (atmosphere) = 101,325 Pa (pascal)
1 atm = 760 mmHg (millimetres of mercury) ≈ 760 torr
1 atm = 1.01325 bar (bar)
1 psi (pound-force per square inch) = 6894.76 Pa

Energy
1 J (joule) = 1 N · m (newton-metre)
1 cal (calorie) = 4.184 J; 1 kcal (kilocalorie) = 4184 J
1 eV (electronvolt) = 1.602×10^{-19} J
1 kWh (kilowatt-hour) = 3.6×10^{6} J
1 BTU (British thermal unit) ≈ 1055.06 J
1 ton TNT (ton of TNT) = 4.184×10^{9} J

Power
1 W (watt) = 1 J/s
1 hp (horsepower) ≈ 746 W
1 MW (megawatt) = 10^{6} W

Radiation Dose
1 Gy (gray) = 1 J/kg
1 rad (rad) = 0.01 Gy

Temperature (differences)
1 K (kelvin) = 1 °C (degree Celsius) *for differences only*

Chemistry
Avogadro's number $N_A = 6.022 \times 10^{23}$ mol^{-1} (per mole)

Light-Travel
1 light-second = 2.998×10^{8} m
1 light-minute = 60 light-seconds; 1 light-hour = 60 light-minutes

Data Boxes (Reference Properties)
Energy densities (approx.)
Gasoline 34.2 MJ/L; Ethanol 30.0 MJ/L
Dry wood 16 MJ/kg; Coal 24 MJ/kg
Diesel 35.8 MJ/L

Miscellaneous
Sucrose M = 342.30 g/mol; Glucose M = 180.16 g/mol
Air density (when cited) 1.20 kg/m^3
Mercury 13.6 g/cm^3; Lead 11.34 g/cm^3

(Optional) Quick Physics Primer for the Curious

1) Dimensions vs. Units. A *dimension* describes the type of quantity (length L, mass M, time T, amount N, etc.). A *unit* is a specific choice for measuring it (metre, foot, second, ...). Dimensional analysis checks that both sides of an equation have the same dimensions.

2) Common derived SI units (from the table).

- Force (newton): $1\,\mathrm{N} = 1\,\mathrm{kg} \cdot \mathrm{m/s^2}$.
- Pressure (pascal): $1\,\mathrm{Pa} = 1\,\mathrm{N/m^2}$.
- Energy (joule): $1\,\mathrm{J} = 1\,\mathrm{N} \cdot \mathrm{m} = 1\,\mathrm{kg} \cdot \mathrm{m^2/s^2}$.
- Power (watt): $1\,\mathrm{W} = 1\,\mathrm{J/s}$.

These connections explain why, for example, $1\,\mathrm{kWh} = 3.6 \times 10^6\,\mathrm{J}$ (power $\times$ time gives energy).

3) Energy vs. Power. Energy is "how much" (tank size); power is "how fast" (flow rate). A 1.50 kW heater uses power; over 25.0 minutes it delivers energy $E = P\Delta t$.

4) Density and surface/areal density. Bulk density uses volume (e.g. $\mathrm{g/cm^3}$); areal density uses area (e.g. $\mathrm{g/m^2}$). Converting $\mathrm{mg/cm^2} \to \mathrm{kg/m^2}$ multiplies by 10^4 (for area) and divides by 10^6 (for mg$\to$kg).

5) Chemistry essentials. One mole contains $N_A = 6.022 \times 10^{23}$ particles. Molar mass (e.g. sucrose 342.30 g/mol) converts between moles and grams. Concentrations like mol/L or mg/L are just ratios with units.

6) Electronvolts. $1\,\mathrm{eV} = 1.602 \times 10^{-19}\,\mathrm{J}$. It's handy for tiny energies per particle; multiply by Avogadro's number to get energy per mole.

7) Radiation dose. A gray (Gy) is energy per mass: $1\,\mathrm{Gy} = 1\,\mathrm{J/kg}$. The older unit rad satisfies $1\,\mathrm{rad} = 0.01\,\mathrm{Gy}$.

8) Light-travel distance. A light-year is how far light goes in a year; a light-minute is how far in a minute. Converting between "light–time" units and metres uses the table's light-second plus time conversions.

9) ppm intuition. For water-like densities, $1\,\mathrm{mg/L} = 1\,\mathrm{mg/kg} = 1\,\mathrm{ppm}$ (by mass). That's why mg/L often equals ppm in dilute aqueous solutions.

10) Significant figures. Match your answer's precision to the given data (usually 2–3 significant figures in these problems). Keep extra digits in intermediate steps and round at the end.